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Impact of Riverine Pollutants on the Water Quality of Lake Chaohu, China

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Impact of Riverine Pollutants on the Water Quality of Lake Chaohu, China

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Abstract. The water environmental capacities for COD_{Mn}, TP, and NH_3-N in Lake Chao were estimated with a zero-dimensional model using Class III water quality as the target. The effects of river pollutants transported by the eight major tributaries on the lake's water quality were then analyzed. The results showed that the water environmental capacities for COD_{Mn}, TP, and NH_3-N in Lake Chao for 2002–2008 were 6.21–6.74, 0.05–0.06, and $1.01–1.27\times10^4$ ton/yr, respectively. The safety margins for COD_{Mn}, TP, and NH_3-N, based on the lake's background reserves, were 5.17–5.86, 0.01–0.03, and $0.89–1.12\times10^4$ ton/yr, respectively. Annually, the river pollutants transported by the tributaries to the lake amounted to $3.58–4.49\times10^4$ ton of COD_{Mn}, $0.19–0.27\times10^4$ ton of TP, and $4.09–5.47\times10^4$ ton of NH_3-N. The total amount of COD_{Mn} exported by the tributaries was less than the water environmental capacity (accounting for 56–68%) and below the safety margin (accounting for 70–82%) of the lake. However, the total amounts of TP and NH_3-N were 3.78–14.75 times higher than the water environmental capacity and the safety margin of the lake. To prevent further deterioration of the lake's water quality, it is critical to strengthen pollution control in the rivers around the lake and to reduce the sources of river pollution.

1. Introduction

In China, all the lakes add up to about 12 million hm^2 of water surface, which accounts for 0.8% of the country's total land area. The water quality of the lakes directly affects the country's overall water quality [1, 2]. Social and economic developments in recent decades have led to large amounts of pollutants being transported to the lakes, causing heavy pollution of their waters. Currently, about 90% of the lakes are in the state of medium to high eutrophication [3, 4]. There have been considerable research and treatment efforts to restore the lake ecosystems and improve their water qualities [5, 6]. However, the level of pollution remains serious. In the long term, the treatment of lakes will continue to be a difficult issue that the official authorities will have to tackle [7, 8].

The treatment of lake pollution has been emphasized and strongly supported since the country's sixth 5-Year Plan [9, 10, and 11]. Although some progress has been achieved, the water quality remains questionable since it is difficult to control the total amount of pollutants being transported to the lakes [12]. In addition, the water environmental capacity of the lakes under varying conditions has not been clearly identified. In the country's eleventh 5-Year Plan, measures for the management of water environments were revised from total target to total capacity controls [13, 14]. Hence, the main task in the national management of lakes is to further research on the water environmental capacities. Pollutants in surface runoffs and point-source discharges are direct sources of lake pollutants [15, 16]. These enter the water of rivers and tributaries and are eventually transported to the receiving water

bodies, including the lakes. Although river pollutants have direct and significant impacts on the water environmental capacities of lakes, quantitative research on the relationship between the two is lacking.

Lake Chao is China's fifth largest freshwater lake. It previously played an important role in agricultural irrigation and supply of potable water for the people of Anhui province [17]. In recent years, the lake has undergone serious eutrophication, resulting in frequent outbreaks of blue-green algal blooms [18, 19]. Hence, it has been earmarked as one of the three key lakes within China to be treated [20]. The local government has repeatedly enacted and amended controls over the total amount of pollutants entering the lake, in the bid to improve its water quality. However, its water environmental capacity for pollutants has not been quantified, thus proper treatment is difficult to administer [21]. In this study, the lake's water environmental capacities for COD_{Mn}, TP, and NH_3-N for 2002–2008 were estimated, using the target of Class III water quality. The impacts of river pollutants transported by the tributaries to the lake on its water environmental capacity were also quantitatively analyzed. These provided scientific data to support future pollution control measures for the lake.

2. Materials and Methods

2.1. Sites Description

Lake Chaohu is one of the five largest fresh lakes in China. Now it is one of the three most eutrophic lakes of China attracting more and more attention in the world-wide-concern. There are thirty three tributaries entering Lake Chaohu. The Nanfei (NFR), Hangbu (HBR), Fengle (FLR), Shiwuli (SR), Pai (PR), Dianbu (DBR), Ershibu (ER), and Zhao (ZR) Rivers are the major tributaries that contribute most of the total water discharge into the lake (about 90%). In this study, six sampling sites were selected throughout the lake, and one sampling site was selected in each of the eight tributaries (Figure 1). The concentrations of COD_{Mn}, TP, and NH_3-N in the sampling stations were monitored monthly during 2002 through 2008.
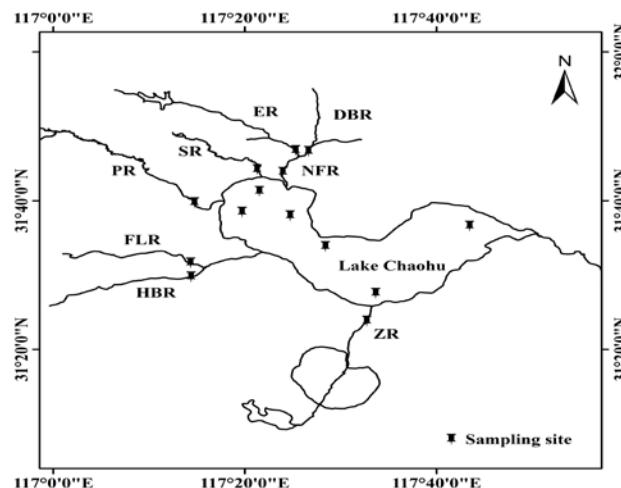
Figure 1. Location of sampling sites in Lake Chaohu and tributaries.

2.2. Calculation of Water Environmental Capacity of Pollutants

The water environmental capacity for COD_{Mn} in Lake Chaohu was calculated using the Vollenweider model [22, 23]:

$$\frac{Vdc}{dt} = Q_iC_i - Q_eC - kCV \tag{1}$$

Where, V is the water volume of the lake (m^3); Q_i is the total water input to the lake (m^3/yr), and Q_e is the total water output the lake (m^3/yr); C_i and C is the concentration of COD_{Mn} in water input to the lake and lake water(mg/L), respectively; k is the biochemical degradation coefficient (1/d).

The water environmental capacity for TP and NH$_3$-N in Lake Chaohu were calculated using the Dillon and Hetianjian models, respectively. The calculation equation of Dillon model [24, 25]:

$$W = Z*A*Cs\ (Qi/V)/\ (1-R) \tag{2}$$

Where, Z is the average depth of lake (m); A is the surface water area of lake (km^2); R is the retention coefficient calculated as R=1- Q_e/Q_i. The meanings of other parameters were same as equation 1.

The calculation equation of Hetianjian model:

$$W = Cs*Z*A*(Qe/V + 10/Z) \tag{3}$$

The meanings of the parameters in equation 3 were the same as described above.

The water environmental capacities for COD$_{Mn}$, TP, and NH$_3$-N in Lake Chao were estimated based on Class III water quality, thus C$_s$ was 6.00, 0.05,1.00 mg/L for COD$_{Mn}$, TP, and NH$_3$-N, respectively.

The total annual amounts of pollutants transported by the tributaries into the lake were calculated as equation 4:

$$F = Cp* \tag{4}$$

Where, F (ton/yr) is the total annual amounts of pollutants transported by the tributaries into the lake, C$_p$ (mg/L) is the annual mean concentration of pollutant, Q (m^3/yr) is the total water discharged to the lake by eight major tributaries.

2.3. Calculation of Total Water Discharge of the Eight Studied Tributaries to Lake

The total water discharge of the eight studied tributaries was estimated using rainfall data and the runoff coefficient within the watershed. The monthly rainfall ranged between 3.5 and 304.2 mm (Figure 2). The many-years' mean runoff coefficient was about 0.46 within the watershed. Then we calculated that the total water discharge to the lake would range from 41.2×10^8—56.2×10^8 m^3 during 2002--2008. This result is very close to the monitored value in other reports (40×10^8 m^3). Considering the water discharge of the eight tributaries to Lake Chaohu (about 90%), it is estimated that about 36.6×10^8--51.1×10^8 m^3 water was discharged to the lake during the study period.
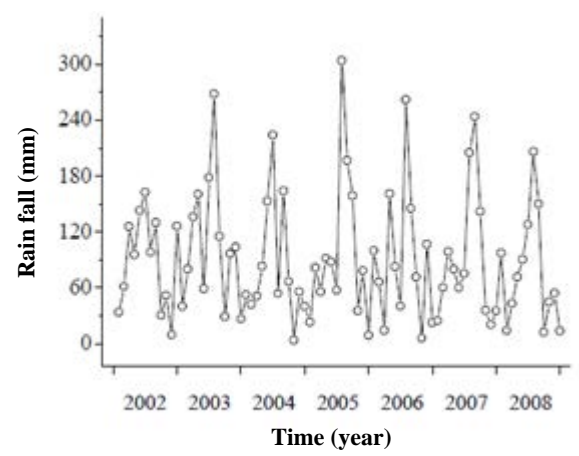

Figure 2. Monthly rainfall within the Lake Chaohu watershed.

3. Results and Discussion

3.1. Water Environment Capacity of COD$_{Mn}$, NH$_3$-N, and TP

The water environmental capacity for COD$_{Mn}$ in the lake ranged 6.21-6.74$\times10^4$ ton /yr from 2002 through 2008, with a mean value of 6.47$\pm$0.18 (SD) $\times10^4$ ton /yr (Figure 3). The water environmental capacity for TP ranged 0.04-0.06$\times10^4$ ton /yr calculated using the Dillon model and 0.06–0.07 $\times10^4$

ton /yr calculated using the Hetianjian model, respectively, with a mean value of 0.06×10^4 ton /yr of the two methodologies. The water environmental capacity for NH_3-N was similarly calculated with the two models; the results were 0.85–1.20 and $1.17–1.35 \times 10^4$ ton /yr, respectively, with a mean value of 1.14×10^4 ton /yr (Figure 4).
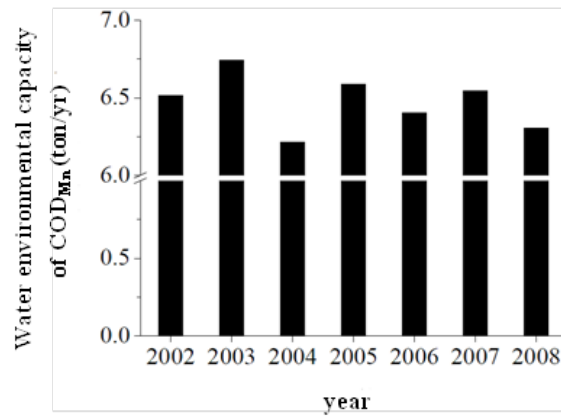
**Figure 3.** Water environment capacity of COD_{Mn} in Lake Chaohu
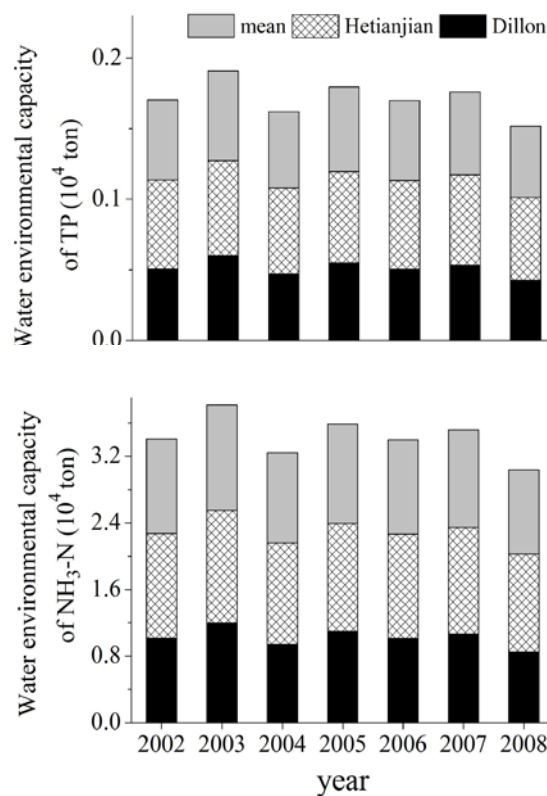
Figure 4. Water environment capacity of TP and NH_3-N in Lake Chaohu

In this study, the water environmental capacities for COD_{Mn}, TP, and NH_3-N in Lake Chao were different with other Chinese lakes under the same water quality target. For example, the study by Yang *et al*. showed that the water environmental capacity for COD_{Mn} was 1.65–2.80 ton /yr while was 58–97 ton /yr for TP in Dian Lake [10]. For Lake Bosten in the Xinjiang province, with the water level varying at 25-90%, the water environmental capacity for COD_{Mn} was $0.46–0.63 \times 10^4$ ton /yr while was

0.08-0.12×10^4 ton /yr for TP [24]. This is because different types of lakes and pollution conditions may result in different water environmental capacities in various lakes. In addition, the interactions and relationships between pollutants, such as the improvement of the environmental capacity for one pollutant may lead to the reduction of other pollutants, may also result in the difference of water environmental capacity for nutrients in the lake [25].

3.2. Safety Margins and Background Reserves of COD_{Mn}, NH_3-N, and TP

The water environmental capacity of a lake refers to the theoretical assimilative capacity of its water under designated conditions. Here, the author is of the view that it is more scientific to use the lake's safety margin to establish the threshold for total emissions of pollutants. To estimate that safety margin, the background reserves of pollutants during the target year must be investigated. During 2002 and 2008, concentrations of COD_{Mn}, TP, and NH_3-N were monthly monitored in the six sampling sites cover the lake. Results showed that the concentrations of COD_{Mn}, TP, and NH_3-N ranged 4.14–13.14, 0.07–0.44 and 0.09–3.71 mg/L respectively, with mean values of 6.01±1.32, 0.19±0.07 and 0.75±0.62 (SD) mg/L respectively (Figure 5). All three pollutants showed higher concentration values in autumn and winter, while no significant difference was detected between the monitoring years. The water quality of Lake Chao maintained at Class IV–V during 2002 and 2008, with COD_{Mn} and TP being the major pollutants.
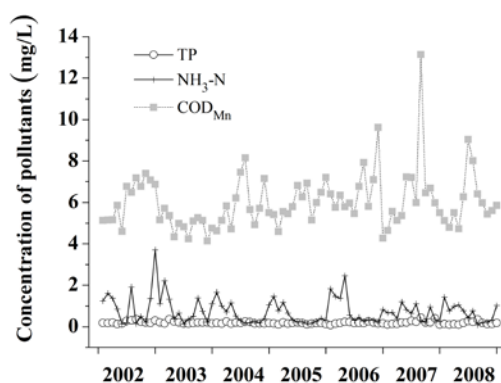
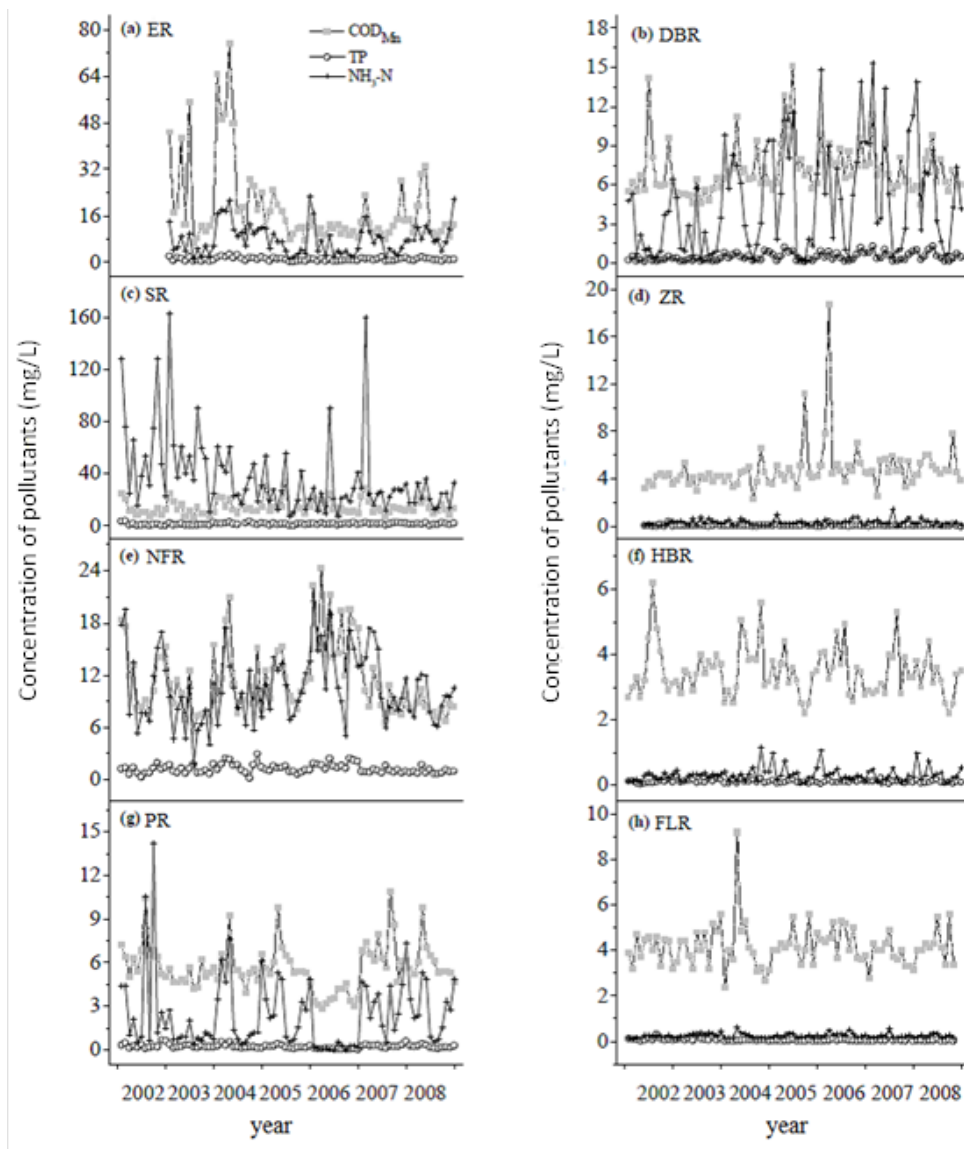**Figure 5.** Monthly concentrations of COD_{Mn}, TP, and NH_3-N in Lake Chaohu

Based on the data of lake's storage capacity over 2002-2008, the annual reserves of COD_{Mn}, TP, and NH_3-N in the lake were estimated to be 0.89–1.21, 0.03–0.04, and 0.09–0.19 ×10^4 ton /yr, respectively. For each year, the annual reserves of COD_{Mn}, TP, and NH_3-N accounted for 13–18%, 56–73%, and 4–14% of the lake's total water environmental capacity, respectively (Figure 6). This means that the water environment has remaining assimilative capacity for all three pollutants. Then we can estimated that for the target of Class III water quality, the safety margins for COD_{Mn}, TP, and NH_3-N in the lake are 5.17-5.86, 0.01-0.03, and 0.89-1.12 ×10^4 ton /yr, respectively.
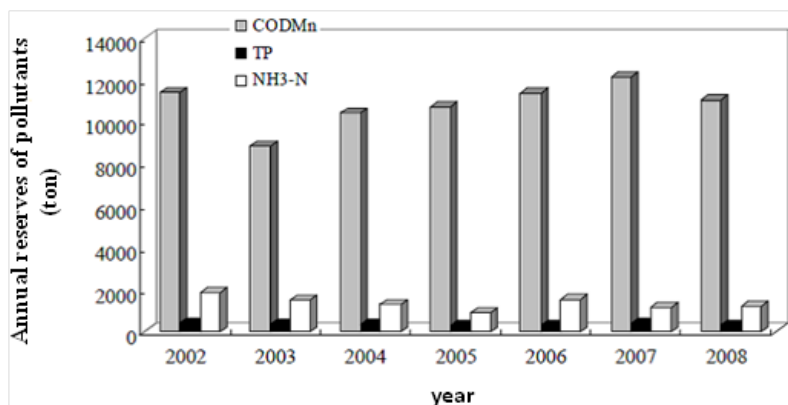
Figure 6. Annual reserves of COD$_{Mn}$, TP, NH$_3$-N in Lake Chaohu

3.3.   Impact of Riverine Pollutants on the Water Quality of Lake Chaohu

The main and direct sources of pollutants for Lake Chao are the tributaries that transport pollutants to it. However, the river pollutants and their impact on water quality in the lake have not been quantified. In this study, the annual flux of pollutants transported by the tributaries to the lake was estimated, and the impact of river pollutants on the lake's water environmental capacity was quantitatively analyzed. The monthly changes in the concentration levels of COD$_{Mn}$, TP, and NH$_3$-N in the eight major tributaries for 2002–2008 are shown in figure 7. The monitoring data showed that the changes in concentrations of COD$_{Mn}$, TP, and NH$_3$-N were 2.2-75.2, 0.01-3.61 and 0.01-163.00 mg/L respectively, with mean values of 8.57±7.38, 0.59±0.68, and 8.08±16.35 (SD) mg/L, respectively.

Figure 7. Monthly concentrations of COD$_{Mn}$, TP, and NH$_3$-N in eight tributaries

Among the tributaries, the pollution level of the Hangbu and Fengle Rivers was relatively low, with the water quality maintained at Class III perennially. However, the pollution level of the other six tributaries was more serious, with the water quality at Class IV–V (inferior). The annual mean concentrations of the three pollutants and the annual total water flowing from the tributaries into the

lake are shown in Table 1. Based on equation (4), it was estimated that the total annual amounts of COD_{Mn}, TP, and NH_3-N transported by the tributaries into the lake were 3.58–4.49, 0.19–0.27, and 4.09–5.47 $\times 10^4$ ton /yr during 2002 and 2008, respectively.

Table 1. Annual mean concentration and export flux of pollutants of eight tributaries

Time	annual mean concentration (mg/L)			total water entering the lake ($10^8\,m^3$)	flux to lake (10^4 ton)		
	COD_{Mn}	TP	NH_3-N		COD_{Mn}	TP	NH_3-N
2002	8.96	0.52	10.40	42.2	3.78	0.22	4.39
2003	9.09	0.52	10.70	51.1	4.64	0.27	5.47
2004	9.28	0.49	10.46	39.1	3.63	0.19	4.09
2005	9.62	0.50	10.72	46.7	4.49	0.23	5.01
2006	9.94	0.51	10.76	42.6	4.23	0.21	4.59
2007	10.24	0.53	11.08	42.7	4.38	0.23	4.74
2008	9.78	0.55	11.33	36.6	3.58	0.21	4.14

A quantitative analysis comparing the total amounts of pollutants from the tributaries with the water environmental capacity and safety margin of Lake Chao was carried out. The results show that for 2002–2008, the total annual amount of COD_{Mn} transported was below the lake's water environmental capacity and safety margin, at the proportion of 56–68% and 70–82% respectively (Figure 8). However, the total annual amount of TP transported was 3.83–4.17 times the lake's water environmental capacity and 7.51–14.75 times its safety margin. For NH_3-N, the total annual amount transported was 3.78–4.29 times the lake's water environmental capacity and 4.30–4.87 times its safety margin. The total annual amounts of TP and NH_3-N transported by the tributaries far exceeded the lake's water environmental capacity. Thus, to control the pollution of Lake Chaohu, it is critical to reduce the yields of pollutants in the watershed.
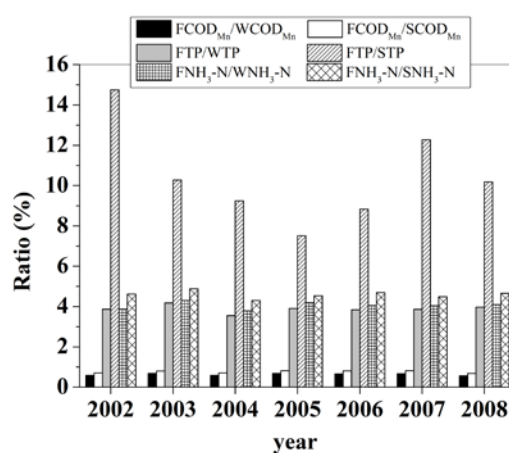
Figure 8. Impact of riverine pollutants fluxes on water environment capacity of Lake Chaohu

($FCOD_{Mn}$, FTP, and FNH_3-N indicate the fluxes of COD_{Mn},TP, and NH_3-N exported by the eight tributaries to the lake; $WCOD_{Mn}$, WTP, and WNH_3-N indicate the water environmental capacity of COD_{Mn},TP, and NH_3-N in the lake; $SCOD_{Mn}$,STP, and SNH_3-N indicate the safety margins of COD_{Mn},TP, and NH_3-N in the lake)

4. Conclusions
In order to analyze the impact of river pollutants transports on the water quality of Lake Chaohu, it is important to estimate the water environmental capacity and the riverine fluxes of pollutants. In this sense, the concentrations of COD_{Mn}, TP, and NH_3-N in Lake Chaohu and the eight major tributaries were monthly monitored during 2002 and 2008, and the water environmental capacities of the three

pollutants in the lake were estimated with a zero-dimensional model using Class III water quality as the target. This is the first study that reports this issue for the region. Our results showed that the water quality of Lake Chao maintained at Class IV–V during 2002 and 2008, with CODMn and TP being the major pollutants. The total annual amount of TP transported was 3.83–4.17 times the lake's water environmental capacity and 7.51–14.75 times its safety margin. For NH_3-N, the total annual amount transported was 3.78–4.29 times the lake's water environmental capacity and 4.30–4.87 times its safety margin. This indicates that it is critical to strengthen pollution control in the rivers around the lake for the restoration of the lake.

5. Acknowledgements

6. References

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